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Monte Carlo simulations of the binary white dwarf population: a progress report

J Camacho¹, S Torres^{1,2} and E García-Berro^{1,2}

¹ Departament de Física Aplicada, Escola Politècnica Superior de Castelldefels, Universitat Politècnica de Catalunya, Avda. del Canal Olímpic 15, 08860 Castelldefels, Spain

² Institute for Space Studies of Catalonia, c/ Gran Capità 2-4, Edif. Nexus 104, 08034 Barcelona, Spain

E-mail: judit@fa.upc.edu

Abstract. We present a detailed Monte Carlo simulator of the population of binary stars within the solar neighborhood. We have used the most updated models for stellar evolution, a complete treatment of the Roche lobe overflow episodes, as well as a full implementation of the orbital evolution. Special emphasis has been placed on processes leading to the formation of binary systems in which one of the members is a white dwarf.

1. Introduction

A wide variety of interesting astrophysical problems, with relevance to many current and planned terrestrial and space-borne observatories like Chandra and XMM-Newton — which are devoted to study X-ray binaries — LIGO and LISA — which will study gravitational radiation sources — or Swift — whose main aim is to study gamma-ray burst progenitors — require extensive population synthesis studies. Additionally, several other interesting problems require modeling the Galactic populations of binary stars. Among these we find the study of Type Ia supernova progenitors, of binary systems containing a white dwarf and a neutron star and of double white dwarf binary systems. Including the selection and observational biases in these kind of studies is of the largest importance and can only be reliably done using a Monte Carlo simulator. Here we describe the preliminary results of such a simulator.

2. Building the sample

A detailed description of our code will be presented in a forthcoming publication. Consequently, here we will only summarize its most important inputs. Our model is based on a Monte Carlo simulator of the disk population of single white dwarfs (García-Berro et al. 1999). The code is based in a random number generator (James 1990) which provides an uniform probability density within the interval (0,1) and ensures a repetition period of 10^{18} , which is virtually infinite for our purposes. The masses of each of the components of the binary system were obtained using a standard initial mass function (Scalo 1988). We only considered stellar masses smaller than $20 M_{\odot}$. Also, a constant star formation rate and a disk age of 11 Gyr were adopted. In addition, orbital separations were randomly drawn according to a logarithmic probability distribution (Nelemans & Tout 2005). The eccentricities were also randomly drawn according to a thermal distribution (Heggie 1975), $f(e) = 2e$ for $0 \leq e \leq 0.9$. Finally, we computed the

Table 1. Summary of the results obtained for the frequency of binary systems that have suffered none or one common envelope episode.

	Relative to the entire binary population	Binary systems with white dwarfs	White dwarf type for each formation channel		
			He	CO	ONe
Case A	15%	0%	0%	0%	0%
Case B	7%	23%	100%	0%	0%
Case C	6%	0%	0%	0%	0%
Case TPAGB	1%	11%	1%	88%	11%
Detached binaries	71%	66%	0%	96%	4%

orbital evolution of the binary taking into account circularization and synchronization (Zahn 1977, 1989; Hut 1981). The stellar ingredients adopted for each of the components of the binary system are the analytical fits to detailed stellar evolutionary tracks of Hurley et al. (2000). These tracks cover the evolutionary stages until the EAGB. Mass loss through stellar winds was not taken into account until the beginning of the thermally pulsing phase TPAGB. In order to model the TPAGB phase we used the radius-luminosity relation of Hurley et al. (2000) but incorporating the luminosity supplied by Marigo et al. (1996) for masses smaller than $5 M_{\odot}$, and from Poelarends et al. (2008) for masses larger than this. For the initial-final mass (which links the mass of the white dwarf with that of its progenitor) we used that of Catalán et al. (2008), complemented with the theoretical fit of Iben et al. (1997) for those progenitors with masses larger than $6 M_{\odot}$.

The Roche lobe radius was modeled according to the prescription of Eggleton (1983), and during the overflow episodes both rejuvenation and ageing were taken into account. Likewise, the overflow treatment was performed following the treatment of Webbink (1985), except when the two stars have a common envelope phase with convective envelopes. In this case we used the double common envelope formalism of Belczynski et al. (2008). During the first common envelope episode gravitational radiation losses and magnetic braking were disregarded. Within these formalisms the mass transfer episodes can be modeled using the radius-mass exponent, $\zeta \equiv d \ln R / d \ln M$. For this we computed ζ_L , which represents the response of the Roche lobe itself, ζ_{ad} which is the adiabatic hydrostatic response of the star, and ζ_{eq} , which is the thermal equilibrium stellar response. It follows that when $\zeta_{ad} < \zeta_L$ a dynamical mass transfer ensues, when $\zeta_{eq} < \zeta_L < \zeta_{ad}$ a thermal mass transfer takes place, whereas nuclear evolution only occurs when $\zeta_L > \zeta_{ad}, \zeta_{eq}$. Additionally, the fraction of mass accreted was modeled taking into account the Kelvin-Helmholtz timescales of both the donor and the accretor.

3. Results

In Table 1 we present a summary of our results. These results are preliminary, as we have only focused on binary systems experiencing at most one common envelope episode. Additionally, in this work we pay special attention to those systems in which at least one of the components is a white dwarf. Systems in which both components are white dwarfs have been counted twice to obtain the frequencies of occurrence. A total of $\sim 9.0 \times 10^4$ binary systems were generated. Of these binary systems, 71% remained detached, 15% underwent a Roche-lobe overflow during the main sequence phase (case A), 7% binaries overflowed its Roche lobe before He ignition (case B), 6% did it before C ignition (case C) and $\sim 1\%$ did it during the TPAGB. As a result, 66% of the binary systems containing a white dwarf are detached systems. The most representative channel of formation of white dwarfs when a mass-transfer episode takes place corresponds to a case B

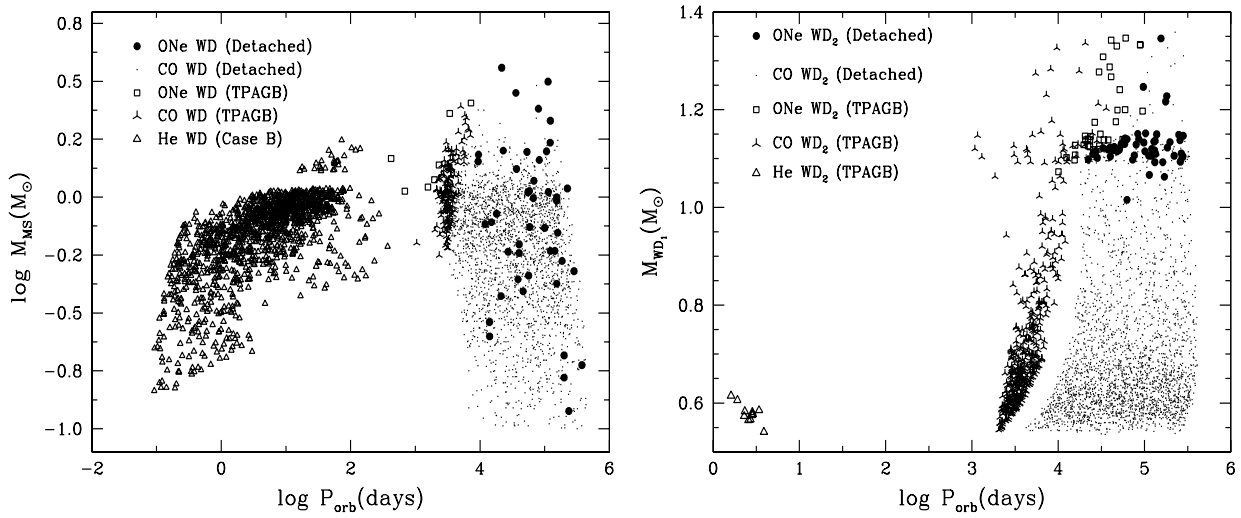


Figure 1. White dwarfs in detached systems or systems which have evolved through one common envelope episode. Left panel: main sequence mass versus orbital period for binary systems composed by a main sequence star and a white dwarf. Right panel: double white dwarf binaries.

Roche lobe overflow (23%), followed by a common envelope episode during the TPAGB phase (11%), whereas no case A or case C Roche lobe overflow results in binary systems containing a white dwarf. Detached binaries in which one of the components is a white dwarf amount to 66%.

If we classify the systems according to the type of the companion we find that He white dwarfs formed in a case B Roche lobe overflow have always main-sequence companions. Here we do not consider those cases in which the resulting system is composed of two He white dwarfs, since these systems are expected to merge due to gravitational wave radiation in a time smaller than the age of the Galaxy. When a case C Roche-lobe overflow is considered the outcome is in all the cases a He white dwarf with a He giant star companion, although the companion star is expected to evolve through a possible second common envelope episode, which we have not yet modeled. For systems resulting from a Roche lobe overflow during the TPAGB phase we obtained that the most favored outcome is that in which a binary system consisting of two CO white dwarfs is formed. This occurs in 59% of the cases. In 25% of the cases the companion of the CO white dwarf is a main sequence star. In 7% of the cases we obtain a double white dwarf binary system composed of a CO white dwarf and an ONe white dwarf. Double ONe white dwarfs occur in 6% of the cases, while systems containing a He white dwarf and a CO white dwarf represent a 2%. Finally, systems in which the primary is an ONe white dwarf and the secondary is a main sequence star occur in only 1% of the cases. Regarding detached binaries, the most common systems are those in which one of the stars is a CO white dwarf while the companion is a main sequence star (65%), followed by those systems in which the two components are CO white dwarfs (30%), while systems consisting of an ONe and a CO white dwarf only amount to a modest 3%. The rest of the possible outcomes are quite infrequent. For instance, systems in which both member of the system are ONe white dwarfs amount to 1%, whereas systems in which the primary is an ONe white dwarf while the secondary is a main sequence star represent 1% of the cases.

The left panel of Fig. 1 shows the characteristics of those systems in which one of the

components is a white dwarf while the companion is a main sequence star. We have chosen to show only detached systems, systems which have undergone a case B episode or systems which have evolved through one common envelope episode during the TPAGB phase. As can be seen, those systems in which the white dwarf has a He core have orbital periods shorter than 10^2 days while when the companion is a CO or an ONe white dwarf the orbital periods are larger than 10^3 days. Moreover, white dwarfs formed during a common envelope episode during the TPAGB present a narrow distribution of orbital periods and have main sequence companions with masses ranging from $\sim 0.6 M_{\odot}$ to $3 M_{\odot}$.

The right panel of Fig. 1 illustrates the properties of our simulated double white dwarf binary systems. Again, we have chosen to show only white dwarfs in detached systems or systems which have evolved through one common envelope episode during the TPAGB phase. For these systems we show the distribution of masses of the most massive white dwarf as a function of the orbital period. As can be seen, those systems in which the primary is a CO white dwarf while the secondary is a He white dwarf have orbital periods around ~ 2 days, while the rest of white dwarf pairs have orbital periods larger than 10^3 days. Also, double CO white dwarf pairs formed from a Roche-lobe overflow during the TPAGB have orbital periods ranging from $\sim 10^3$ to $\sim 10^4$ days, while detached double white dwarfs present a wider range of orbital periods. In the same way, those systems in which both components are ONe white dwarfs formed during a common envelope episode during the TPAGB have shorter orbital periods than those formed in detached systems.

4. Summary and conclusions

We have presented the preliminary results obtained using a Monte Carlo simulator of the Galactic population of binary systems containing at least one white dwarf. Specifically, we have performed an study of those systems in which one of the components is a white dwarf and are either detached systems or have suffered only one common envelope phase. Special emphasis has been placed in studying the resulting orbital parameters (eccentricities and orbital separations) as a previous step to compare the theoretical results with observational data.

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